



Full length article

Cognitive and visual demands, but not gross motor demand, of concurrent smartphone use affect laboratory and free-living gait among young and older adults

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ABSTRACT

Background: As smartphones are an integral part of daily activities, understanding the underlying mechanism associated with concurrent cell phone use while walking may help reduce the risks of injury.

Research question: This study examined the effect of cognitive, visual, and gross motor demands while using a phone during gait among young and older adults in the laboratory and free-living environments.

Methods: Twelve young and twelve older adults walked along a 10-m walkway under five conditions: single-task walking (Walk), walking and bi-manually holding a phone (Walk-Hold), walking while looking at a phone held in front of the participants (Walk-Look), walking while answering questions (Walk-Answer), and walking while texting (Walk-Text). All conditions were performed in laboratory and free-living environments. Gait velocity, step time, step length, and cadence were obtained using a smartphone with a built-in accelerometer attached to the body. The dual-task cost (DTC) was also assessed. A three-way ANOVA was utilized for all parameters.

Results: While no three-way interactions were found for any parameter, group \times condition interactions were significant for gait velocity, step time, step length, cadence and their corresponding DTC. Decreased gait velocity, step length and cadence, with increased step time was demonstrated during Walk-Look, Walk-Answer, and Walk-Text, compared to Walk and Walk-Hold. While older adults markedly changed their gait during Walk-Answer and Walk-Text, these changes were less pronounced among young adults.

Significance: Visual and cognitive demand while concurrently using a phone influenced gait, especially among the elderly. Environment did not accentuate gait alterations during concurrent phone use. Therefore, smartphone technology should be developed to detect dual-task walking and temporarily modify functionality to reduce risk of injury from divided attention.

1. Introduction

As smartphones become an integral part of life, the use of smartphones while performing daily activities such as walking is common. Phone use while walking has been linked with an increased number of accidental injuries, with the percentage of smartphone-related pedestrian injuries rising from 0.58% in 2004 to 3.67% in 2010 [1]. Since the incidence of smartphone-related injury among pedestrians is growing faster than among drivers [1] or when used in the home [2], concerns regarding safety of this activity have been raised. A number of studies have investigated phone use while walking to assess dual-task performance [3–5], to examine unsafe behavior during walking and crossing

the street [6–9], and to predict the risk of falls associated with phone use [10]. Most of these studies have investigated concurrent phone use among young adults. Results revealed that when engaged in phone use, young adults walked slower [4], increased deviation from the pathway [4], modified their posture [11,12], and increased risky behavior during walking and crossing the street (e.g. less likely to notice objects and people in the surrounding environment; more likely to look away from the street and get hit by a vehicle) [6–9].

To our knowledge, only three studies have examined walking performance during phone use among older adults. Takeuchi and colleagues showed that concurrent smartphone use deteriorated both cognitive and walking performance in older adults, but not in young adults

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[13]. Only older adults walked with a longer step time and made more mistakes in the phone gaming condition relative to the single-task conditions. In contrast, Kao and colleagues found a comparable effect of phone use between young and older adults [3]. Specifically, the concurrent phone dialing and Symbol Digit Modalities tasks (SDMT) compromised mediolateral stability while walking in young and older adults equally. Because both the phone dialing task and SDMT required the participants to hold and look at the phone or the key sheet, it was then suggested that restricted visual resources and decreased arm swing may contribute to deteriorated walking performance with concurrent phone use. Recently, Krasovsky and colleagues found a similar texting effect on gait among young and older adults in the indoor environment [14]. However, dual-task deterioration was more pronounced among older adults in the outdoor setting.

Understanding the underlying mechanism associated with concurrent phone use while walking may help reduce the risks of injury. To examine the physical and cognitive requirements of the texting-while-walking task, experienced texters were asked to walk under varying physical and cognitive demand conditions [5]. Only the physical demand conditions (i.e. walking while holding the phone and walking while texting) significantly increased the frontal plane margin of stability during walking, both of which required participants to hold and look at the phone, thus limiting visual attention to the environment and modifying their natural arm swing [5]. The results from this study support the notion that physical demand (i.e. visual resources and arm swing), not cognitive demand, play a significant role in modifying walking performance while using a phone.

Existing data associated with phone use while walking is limited to gait assessment in a controlled laboratory. Little is known about the effect of phone use in free-living environments. Plummer and colleagues examined the effect of environmental settings on dual-task performance during texting while walking in young adults [15]. Participants were asked to walk while texting with and without task prioritization in both laboratory and real-world settings. The results showed that young adults focused on the texting task when they were in the laboratory, but focused equally on both texting and walking tasks in a real-world setting. However, the effect of environment on smartphone use while walking is still largely unknown among older adults.

Even though a body of literature suggests that concurrent phone use affects gait in young adults and jeopardizes the safety of pedestrians, a paucity of research has examined the influence of phone use among elderly. Additionally, several important issues regarding the factors associated with smartphone use while walking remain unclear. First, although smartphone use while walking may cause cognitive interference, reduced visual awareness about the surroundings, and decreased arm swinging, few studies have examined these factors separately. Most studies require participants to walk while holding and either looking at a phone or texting [3–5]. Consequently, the degree to which cognitive demand and physical demand (i.e. visual interference, and reduced arm swing) may have contributed to the results cannot be determined. Second, it is not known whether laboratory-based studies accurately reflect performance in the real world.

Therefore, the purposes of this study were to examine 1) the effect of cognitive, visual, and gross motor (i.e. reduced arm swing) demands while using a phone during gait; 2) the effect of concurrent phone use on gait in young and older adults; and 3) the effect of environmental setting on concurrent phone use while walking. We hypothesized that 1) visual demand during the “walking while looking at a phone” and “walking and texting on a phone” conditions would pose the greatest gait modification in both young and older adults compared to cognitive or gross motor demanding tasks; 2) concurrent phone use would result in gait modifications (i.e. slower gait speed, shorter step length, and longer step time) and these changes would be more pronounced among older adults; and 3) gait alteration during concurrent phone use would be more evident in the free-living environment compared to the laboratory setting.

2. Methods

2.1. Participants

Participants were recruited into the study via leaflets and announcement through community leaders and primary health care providers. Young and older adults were included if they were between the ages of 18–30 years or over 65 years of age, respectively. Additionally, all participants were able to walk at least ten meters without the assistance of another person or walking aid, and had used a touchscreen smartphone for at least two months, with greater than 200 text messages sent per month [5]. Exclusion criteria were unstable medical conditions, presenting with severe neurological, musculoskeletal, or cardiopulmonary problems, having visual impairment uncorrectable with conventional lenses, and upper or lower limb amputation. The study was approved by the University’s Research Ethics Committee (number AMSEC-60EX-072) and written informed consent was obtained from each participant prior to enrollment into the study.

2.2. Experimental design

Following informed consent, participants provided self-reported information on age, sex, medical history, and smartphone usage. Participants then underwent six testing conditions (Fig. 1): A) texting tasks while standing (Text; cognitive control); B) single-task walking (Walk; gait control); C) walking and bi-manually holding a phone in the texting position (Walk-Hold; gross motor demand); D) walking while looking at a phone held in front of the participants by a custom-made apparatus (Walk-Look; visual demand); E) walking and answering questions (Walk-Answer; cognitive demand); and F) walking and texting on a phone (Walk-Text; cognitive, visual, and gross motor demand). All conditions were repeated three times, with mean values used for further analysis.

For Text, participants were asked to respond to a single question orally presented by the investigator by texting on the phone while standing. A 30 s time frame was provided for participants to list their responses. For all walking tasks, participants were asked to walk at their self-selected comfortable walking speed across a 10-meter walkway. For Walk-Hold, the smartphone was held with both hands, with participants instructed to not look at the phone and no external focus specified. For Walk-Look, a custom-made apparatus (Fig. 2) was placed on each participant, with the smartphone adjusted to their normal texting position. Participants were instructed to always look at the phone while walking. During Walk-Hold and Walk-Look, the smartphone’s front camera recorded the participant’s gaze in order to estimate the amount of time the participant looked at the smartphone while walking in order to assess adherence. During Walk-Answer and Walk-Text, each participant walked while simultaneously answering questions verbally or by texting. The questions presented for all cognitive tasks were randomly chosen from a similar topic regarding their daily activities (e.g. What are your favorite foods?), with different questions asked to prevent learning. Cognitive outcome variables included response rate and accuracy. For all phone conditions, the participants interacted with an ASUS ZenFone 4 Max Pro smartphone. Participants were given time to be acquainted with the phone and texting application prior to data collections.

All conditions were performed in the laboratory and in the free-living environment. The laboratory environment was a quiet, clutter-free research lab with dimensions of 13m*13m*5 m (width*length*height). The free-living environment was a busy 6m*16m*5 m walkway outside the laboratory. The walkway connected to a parking lot, coffee shop, and was situated along a pedestrian thoroughfare. The order of all conditions was randomized, with the order of environmental setting counterbalanced.

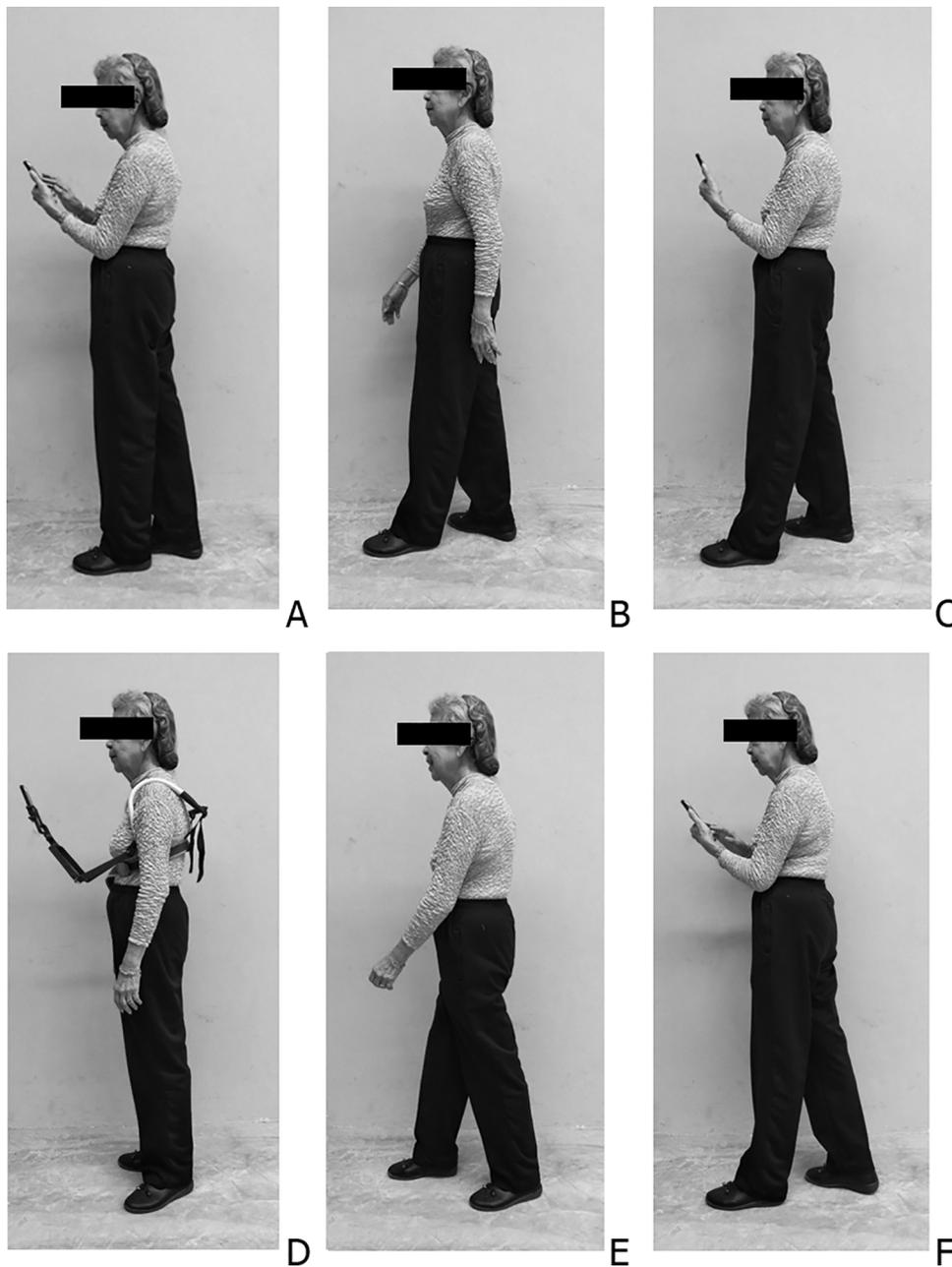


Fig. 1. Testing conditions undertaken by participants. Conditions included standing while texting (A; cognitive control), single-task walking (B; gait control), walking while bi-manually holding a phone in the texting position (C; gross motor demand), walking while looking at a phone held in front of the participants using a custom-made apparatus (D; visual demand), walking and answering questions (E; cognitive demand), and walking while texting on a phone (F; cognitive, visual, and gross motor demand).



Fig. 2. Custom-built apparatus to hold smartphones in the texting position.

2.3. Data acquisition and analysis

To measure steady state gait, only the middle eight meters was used to examine gait parameters to eliminate effects of acceleration and deceleration. A custom-written Android application [16] was used to collect tri-axial acceleration data on another smartphone (Samsung J7 plus, Android 7.1.1) with a built-in accelerometer sensor (STM LSM6DSL, ± 4 g range, 0.0012 m/s^2 resolution). The smartphone was attached using a velcro strap to the third lumbar spinous process and collected acceleration data at 100 Hz. A custom-built MATLAB (Mathworks Inc., Natick, MA) program was used to assess gait parameters offline.

Spatiotemporal gait characteristics (gait velocity, step time, step length, and cadence) both in the laboratory and free-living

environments were obtained as previously described using a methodology that has been shown to be valid and reliable [17]. Briefly, all acceleration data were resampled to a frequency of 100 Hz, with data in all three axes filtered using a 4th order Butterworth low-pass filter with a 20 Hz cutoff frequency. Antero-posterior (AP) accelerations were further filtered using a 4th order Butterworth low-pass filter with a 2 Hz cutoff frequency. Positive peaks in the filtered AP axis were identified as heel strikes, with step time computed as the time difference between these heel strikes. Step length was computed using the equation:

$$SL = 2 * \sqrt{2 * h * l - h^2}$$

where *SL* is the step length, *l* is the participant's leg length and *h* is the change in vertical position. *h* was computed by double integrating the vertical acceleration data, and high pass filtering the result with a 4th order Butterworth filter having a 0.1 Hz cutoff frequency to remove integration drift. Gait velocity was computed as the average of all step velocities, where step velocity was the quotient of step length and step time. Cadence was assessed using the number of steps and time duration for each trial in units of steps per minute.

The dual-task cost (DTC) was defined for gait velocity, step length, and cadence using the equation:

$$DTC = \text{single task value} - \text{dual task value}$$

With the DTC for step time computed using the same equation, but with an opposite sign.

During texting tasks, a custom-written application recorded key-strokes and typing duration. For verbal answering tasks, responses were recorded by an investigator. Since task duration was not equivalent across conditions, accuracy was evaluated as the number of correct responses versus the total number of answers provided and the rate of response was calculated as the number of answers per minute. During the free-living environment conditions, a video camera was used to record density of pedestrian traffic, collisions with other persons, and path adjustments [11].

2.4. Statistical analysis

Skewness of the data for all parameters were investigated prior to utilizing statistical tests of significance. Skewed data were analyzed using non-parametric methods, otherwise parametric tests were applied. A three-way mixed-effects ANOVA was used for all four gait measures and texting performance, with group as the between-subjects factor, testing conditions and environment setting as within-subject factors. If the three-way interaction was non-significant, all possible two-way interactions were investigated. Main effects were considered only if no two-way interactions were found. If there were any interaction effects, the differences were then estimated at each level. A two-way mixed-effects (group × environment) ANOVA was used for verbal response. Statistical significance was set at an alpha level of $p < 0.05$ with unadjusted *p*-values reported. For participant demographics, Fisher's exact test was used for gender, *t*-tests used for weight, height, and smartphone experience, and the Wilcoxon Rank Sum test used for smartphone usage and activity. Outliers which were not the result of technical error were included in the analysis. All data were analyzed using SPSS 17.0 (IBM Inc., Armonk, NY).

3. Results

3.1. Participants

Twelve young adults and twelve older adults were recruited for this study. There were no group differences in weight, height, and smartphone experience (Table 1; $p > 0.05$). Smartphone usage was approximately five hours greater per day among young adults, compared to older adults ($p < 0.001$). Due to technical error, text responses for one trial were not collected.

3.2. Effect of cognitive, visual, and motor demands on gait

The three-way group × condition × environment interaction was not significant for gait velocity, step time, step length, or cadence (Table 2). Furthermore, there was an absence of group × environment or condition × environment interactions as well as a main effect of environment for all gait parameters. However, the group × condition interactions were significant for gait velocity ($p < 0.001$), step time ($p = 0.001$), step length ($p < 0.001$), and cadence ($p < 0.001$). When comparing the walking conditions for each age group, we find that both groups walked slower, demonstrated longer step times, shorter step lengths, and lower cadence during all dual-task walking conditions, except Walk-Hold, compared to single-task walking. While older adults greatly modified their gait during Walk-Answer and Walk-Text, these changes were less pronounced among young adults. Furthermore, only older adults showed gait modifications during Walk-Answer compared to Walk-Look. The DTC findings matched those from the raw data (Fig. 3).

When comparing the age groups for each condition, we find that older adults ambulate differently than young adults only during Walk-Text with significant differences for every variable. Groups differences in the DTC of step time and cadence were also demonstrated during Walk-Answer. No group differences were found during Walk-Hold or Walk-Look.

For the Walk-Hold and Walk-Look conditions, both groups adhered to the protocol instruction regarding whether or not to look at the phone while walking. Additionally, video analysis demonstrated no collisions or path adjustments during any free-living walking trials, with a comparable level of crowdedness across participants.

3.3. Effect of cognitive, visual, and motor demands on response accuracy and rate of response

No group × condition × environment interaction was found for accuracy ($p = 0.65$) and rate of texting response ($p = 0.96$; Table 3). There was also an absence of a group × environment interaction, a condition × environment interaction, or a main effect of environment. However, there was a group × condition interaction for accuracy ($p = 0.04$). When comparing the walking conditions for each age group, older adults decreased their texting accuracy during the Walk-Text condition compared to the Text condition ($p = 0.001$). No such differences were demonstrated for young adults ($p = 0.48$). When comparing the age groups for each condition, we find that young adults typed with a higher accuracy than older adults under Text ($p < 0.001$) and Walk-Text conditions ($p < 0.001$).

For rate of response, there was a significant main effect of group ($p < 0.001$) and condition ($p = 0.001$). Young adults responded faster than older adults (110.6 vs. 40.3 characters/min; $p < 0.001$). Furthermore, all participants texted with a faster rate of response during the Text condition compared to the Walk-Text condition (81.0 vs. 69.9 characters/min; $p = 0.001$).

For verbal accuracy under the Walk-Answer condition, no group × environment interaction ($p = 0.25$) or main effect of group ($p = 0.49$) and environment ($p = 0.51$) were shown. No differences were demonstrated between young and older adults (mean(SD): 98.9(1.9)% and 97.9(7.1)% accuracy, respectively) or between laboratory and free-living environments (mean(SD): 97.9(7.0)% and 98.9(2.3)% accuracy, respectively).

4. Discussion

The aim of this study was to investigate which domain (cognitive, visual, or gross motor) contributes to gait deterioration when concurrently using a smartphone among the young and elderly in both laboratory and free-living environments. Findings from this study partly support our hypothesis that visual demand during walking would

Table 1
Demographic data for young and older adults.

Measure	Young (N = 12)		Older (N = 12)		p-value
	Mean (SD)	Median (IQR)	Mean (SD)	Median (IQR)	
Age (years)	22.7 (1.8)	22.5 (21.0–24.0)	73.5 (5.6)	71.5 (69.0–78.0)	–
Females (n)	8		10		0.64
Weight (kg)	56.7 (9.9)	55.9 (49.0–63.4)	59.3 (7.2)	58.6 (53.0–64.0)	0.47
Height (m)	1.61 (0.07)	1.59 (1.57–1.66)	1.58 (0.06)	1.59 (1.53–1.63)	0.29
Smartphone experience (years)	6.5 (1.4)	6.5 (5.0–7.8)	5.3 (3.2)	5.0 (3.0–7.0)	0.24
Smartphone usage (hours/day)	8.5 (3.8)	7.6 (5.7–9.3)	3.1 (2.3)	2.0 (1.3–4.2)	< 0.001
Smartphone activity (mins/day)					
Social networking	212.5 (145.5)	180.0 (120.0–240.0)	122.5 (85.3)	90.0 (60.0–180.0)	0.06
Watching videos	87.5 (62.0)	90.0 (37.5–120.0)	5.0 (17.3)	0.0 (0.0)	< 0.001
Web search	65.0 (42.1)	60.0 (37.5–112.5)	0.0 (0.0)	0.0 (0.0)	< 0.001
E-mail	12.1 (19.0)	0.0 (0.0–26.3)	0.0 (0.0)	0.0 (0.0)	0.04
Playing games	57.5 (63.3)	45.0 (0.0–120.0)	30.0 (103.9)	0.0 (0.0)	0.03
Taking photos	9.6 (17.9)	0.0 (0.0–18.8)	0.0 (0.0)	0.0 (0.0)	0.09
Listening to music	55.0 (45.8)	60.0 (7.5–105.0)	9.2 (18.8)	0.0 (0.0–15.0)	0.01
Phone call	22.9 (21.6)	25.0 (0.0–30.0)	13.3 (15.0)	5.0 (0.0–30.0)	0.33

Note: SD; standard deviation, IQR; interquartile range.

Table 2
Gait parameters (mean (SD)) for young and older adults under five testing conditions in the laboratory and free-living environments.

Variable	Group	Environment	Walk	Walk-Hold	Walk-Look	Walk-Answer	Walk-Text	Interaction effect (G × C × E)
Gait velocity (m/s)	Young	Lab	1.30 (0.17) *†‡	1.33 (0.19) *†‡	1.19 (0.17) ‡	1.14 (0.19) ‡	1.02 (0.18)	0.38
		Free	1.30 (0.23)	1.30 (0.22)	1.19 (0.19)	1.11 (0.24)	1.03 (0.19)	
	Older	Lab	1.29 (0.17) *†‡	1.28 (0.16) *†‡	1.22 (0.19) ‡	0.99 (0.12) ‡	0.73 (0.21) §	
		Free	1.28 (0.12)	1.29 (0.11)	1.20 (0.13)	1.01 (0.14)	0.75 (0.14)	
Step time (ms)	Young	Lab	513.4 (34.1) *‡	511.0 (32.3) *†‡	523.5 (32.0) ‡	540.3 (42.9)	559.0 (43.0)	0.33
		Free	511.7 (42.1)	513.2 (38.0)	516.6 (40.1)	543.2 (50.9)	555.6 (45.1)	
	Older	Lab	510.7 (41.7) *†‡	512.1 (38.0) *†‡	516.4 (42.2) ‡	587.4 (69.1) ‡	614.7 (73.0) §	
		Free	501.7 (34.1)	499.6 (34.1)	510.7 (30.6)	584.3 (89.9)	623.6 (64.7)	
Step length (m)	Young	Lab	0.66 (0.08) *†‡	0.68 (0.09) *†‡	0.62 (0.08) ‡	0.61 (0.09) ..	0.57 (0.09)	0.31
		Free	0.66 (0.09)	0.66 (0.10)	0.61 (0.08)	0.59 (0.10)	0.57 (0.09)	
	Older	Lab	0.65 (0.07) *†‡	0.65 (0.06) *†‡	0.62 (0.07) ‡	0.57 (0.06) ‡	0.44 (0.11) §	
		Free	0.64 (0.05)	0.64 (0.05)	0.61 (0.05)	0.58 (0.05)	0.46 (0.06)	
Cadence (Steps/min)	Young	Lab	117.4 (7.8) *†‡	117.9 (7.7) *†‡	115.1 (7.0) ‡	111.8 (9.4)	107.9 (7.8)	0.16
		Free	118.0 (9.7)	117.5 (8.7)	116.8 (9.4)	111.4 (10.7)	108.7 (8.9)	
	Older	Lab	118.3 (9.5) *†‡	117.8 (8.6) *†‡	117.0 (9.5) ‡	103.5 (11.3) ‡	99.3 (11.6) §	
		Free	120.1 (8.0)	120.6 (8.3)	118.0 (6.9)	104.7 (13.6)	97.3 (10.1)	

Note: G – Group; C – Condition; E – Environment; *Significant difference from Walk-Look; †Significant difference from Walk-Answer; ‡Significant difference from Walk-Text; No differences were found between Walk and Walk-Hold for any variable; §Significant difference between young and older adults.

contribute greatest to gait modifications and that changes would be more pronounced among older adults. All adults demonstrated decreased gait velocity, step length, and cadence, with increased step time, during Walk-Look compared to Walk and Walk-Hold. To guide locomotion, vision allows for the perception of stimuli arriving from the environment and of limb position and movement [18]. However, during concurrent smartphone use, visual attention directed towards the phone lead to decreased awareness of external cues and self-motion. Additionally, head and trunk orientation are limited while looking at a smartphone screen, thereby inadequately updating peripheral visual information for navigation and affecting proper gait modifications [19].

Both groups demonstrated decreased gait velocity, step length, and cadence, as well as increased step time during Walk-Answer, compared to Walk and Walk-Hold. Gait changes are further accentuated during Walk-Text. These results indicate that cognitive demands of smartphone use play a vital role in modifying gait performance in all adults. This is consistent with previous research [8,9,20] which found that participants walked slower and were less likely to successfully cross the street while concurrently talking or texting on a phone than did undistracted participants. In the current study, gait compensatory mechanisms may be a result of divided attention onto the secondary task, especially during the texting task, where not only were communication

exchanges required but participants also had to read (visual demand) and type (gross and fine motor demand) which may cause greater cognitive distraction [8].

Furthermore, only older adults showed gait alterations and increased DTC during Walk-Answer compared to Walk-Look. One possible explanation is that older adults are allocating greater attentional resources to the cognitive task in order to successfully complete the dual-task. This is demonstrated through the equal accuracy on the Walk-Answer task among young and older adults. Alternatively, this might result from diminished cognitive ability, which has previously been shown to reduce gait velocity and increase falling risk among older adults [21,22]. However, tests of cognitive performance were not administered in this study.

Contrary to our hypothesis, results revealed that there was no effect of environment on healthy adult gait. These results are in contrast to Krasovsky and colleagues who found increased DTCs of gait parameters and reduced texting accuracy among older adults in the outdoor environment [14]. Data from the current study were obtained from only a few steps in a busy environment, which may not be sufficiently distracting as no collisions or path adjustments were observed, and thus not representative of gait performance in a real-world setting. However, these findings are similar to those of Plummer and colleagues who

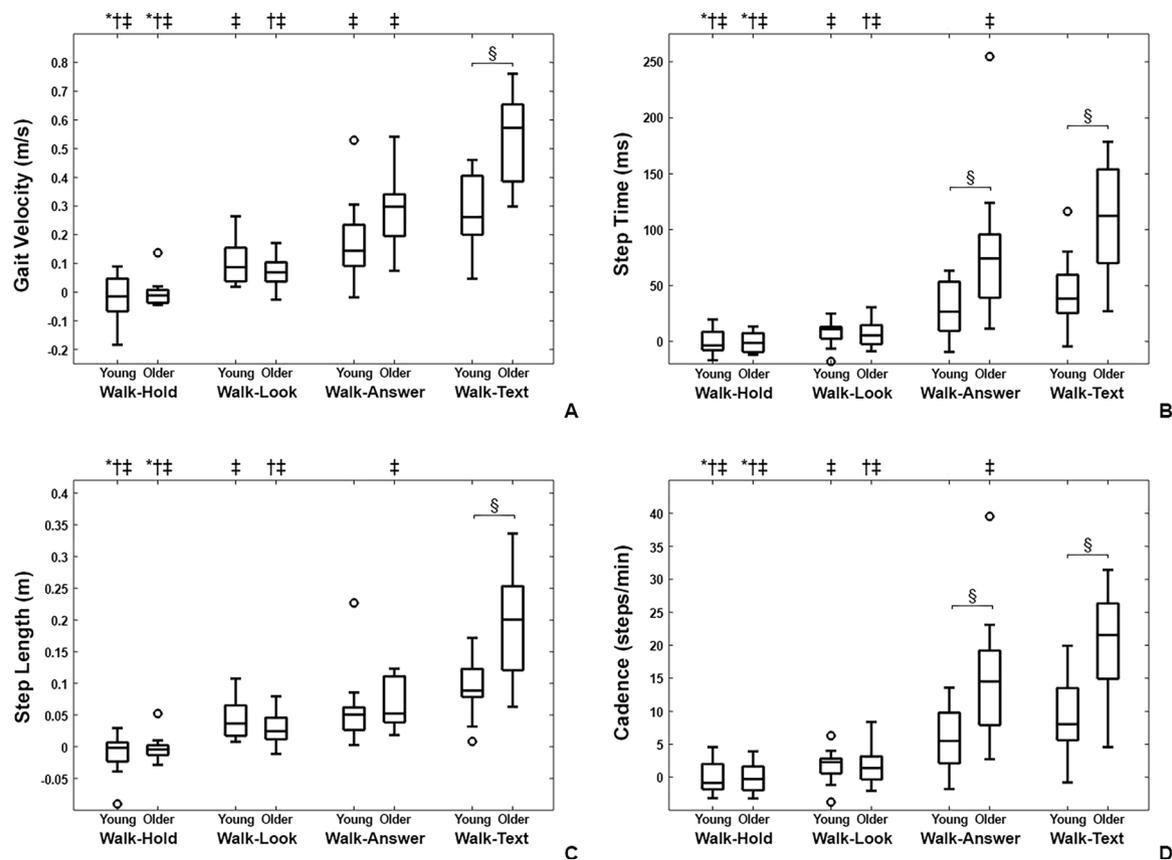


Fig. 3. Dual-task cost for gait parameters across group and condition. The *symbol indicates significant difference compared to the Walk-Look condition. The † symbol indicates significant difference compared to the Walk-Answer condition. The ‡ symbol indicates significant difference compared to the Walk-Text condition. The § symbol indicates significant difference between young and older adults.

found that young adults could flexibly prioritize their attention when concurrently walking and texting, regardless of environment [15].

In conclusion, this study provides evidence that cognitive and visual demands strongly influenced gait while concurrently using a phone, particularly among older adults. Alternatively, walking without arm swing did not alter gait, as a mobile phone is not considered a heavy load [23]. A longer walking distance with a heavier load may accentuate the effect of gross motor demand associated with phone use on gait. This study has a few limitations. First, spatiotemporal gait parameters only provide an indirect measure of walking stability. While future studies should investigate balance control during gait and concurrent smartphone use, assessment of spatiotemporal parameters are a basic prerequisite for gait analysis. Second, this study asked participants to walk straight over level surface, which was not representative of everyday walking, where people have to turn, avoid obstacles, and modulate gait speed. Furthermore, measures such as gait variability

cannot be ascertained over the 8-meter walking distance. Similarly, a small number of responses are possible, as participants texted approximately 2–4 words during the Walk-Text task and responded with 6–7 words during the Walk-Answer task, over the short walking distance. However, the significant gait modifications indicate that participants were distracted during the walking tasks due to cognitive demands and visual interference. Dual-task walking should then be minimized, as it places older adults at a greater risk of injury. If unavoidable, appropriate dual-task training with attentional focus can mitigate risk [24]. Furthermore, smartphone technologies should be developed to detect user activity and simultaneously manipulate the user interface to reduce cognitive-visual-gait interference and prevent subsequent injury.

Table 3

Response accuracy and rate of response (mean (SD)) for young and older adults during Text and Walk-Text conditions in the laboratory and free-living environments.

Variable	Group	Environment	Text	Walk-Text	Interaction effect (G × C × E)
Accuracy (% correct)	Young	Lab	90.7 (6.6)	90.7 (8.1)	0.65
		Free	90.1 (13.2)	83.2 (13.7)	
	Older	Lab	57.0 (27.1)	45.6 (28.7)	
		Free	62.1 (26.3)	37.3 (31.2)	
Rate of response (characters/min) ^{ab}	Young	Lab	110.7 (27.2)	103.6 (18.9)	0.96
		Free	121.0 (12.8)	107.0 (23.4)	
	Older	Lab	43.5 (22.9)	35.0 (19.3)	
		Free	48.6 (18.9)	33.9 (19.4)	

Note: G – Group; C – Condition; E – Environment. *Significant difference between Text and Walk-Text; §Significant difference between young and older adults; ^aSignificant group main effect; ^bSignificant condition main effect.

Conflict of interest statement

None.

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